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Static pressure effects on stern lift and drag of the XR-3 captured air bubble testcraft.

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STATIC PRESSURE EFFECTS ON STERN SEAL LIFT AND DRAG OF THE XR-3 CAPTURED AIR BUBBLE TESTCRAFT

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Monterey, California

THESIS

STATIC PRESSURE EFFECTS

ON

STERN SEAL LIFT AND DRAG

OF THE XR-3 CAPTURED AIR BUBBLE TESTCRAFT

by

John Scott Payne

December 1975

Thesis Advisor: D. M. Layton

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Static Pressure Effects
on
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of the XR-3 Captured Air Bubble Testcraft

by

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requirements for the degree of

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I. INTRODUCTION

The continuing interest in a highly mobile, high speed surface Navy has generated two, one-hundred ton, surface effects ships under the sponsorship of the Surface Effects Ship Projects Office in conjunction with the Bell Aerospace Company and Aerojet-General Corporation. While these two research vehicles have done much to expand the investigation of air custion vehicles in general, their very size puts limitations on the amount of experimental work that can be carried on without major component modification or costly restructuring of sub-components. The Naval Postgraduate School's surface effects ship testcraft, the XR-3, fulfills the need for a relatively low cost evaluation platform. In this capacity the XR-3 has for five years operated under the auspices of the Aeronautics Department, on Lake San Antonio, one hundred miles south of Monterey, California. The vessel weighs approximately three tons with a beam of twelve feet and a length of twenty four feet. Unlike hovercraft, captured air bubble vehicles like the XR-3 never lift their hulls completely from the surface of the water. Flexible seals at front and rear trap air in a "bubble" between rigid sidewalls. An overpressure is maintained within the "bubble" by means of ducted air from fans carried in the vehicle. This overpressure reduces, directly, the interior waterline of the craft, while lifting the vehicle partially and thus to a lesser extent reducing the external waterline. The flexible seals allow the ship to accelerate, ride over its own bow wave, and cruise, while maintaining plenum or "bubble" pressure. The advantages of reducing hull drag by the reduction in wetted surface area and the "swallowing" of the bow wave are obvious. Reference 1 provides a complete look at the resulting high levels of performance obtained with the XR-3 in tests run in 1973.

Efforts to further improve the performance of the

captured air bubble type vehicle will depend on the degree to which drag can further be reduced in the hull- to-water and the hull-to-air interfaces. It is in this context that this project developed. As a first step in attempting to reduce drag it is essential that existing drag sources be isolated and detailed. G. H. Elsley and A. J. Devereux point out in Ref. 2 the difficulties associated with drag determination. "Drag estimation is by no means an exact science and the drag picture of an ACV is considerably more complicated than that of a low speed aircraft since drag components arise both from its passage through the air and from the surface over which it is operating." Total drag determinations were made for the XR-3 test vehicle in 1973 and may be found in Ref. 1. No attempt could be made at that time to determine what portion of the drag was associated with sidewall immersion, seal drag, or aerodynamic drags on the sail area of the vessel. This paper will deal exclusively with the lift and drag present on the rear seal of the XR-3 as a result of static pressures along its surface. A similar analysis of pressure forces present on the rear of the bow seal will be necessary before valid conclusions can be drawn relating the total drag of the ship with the drag of the rear seal. It may be readily seen that the overpressure present as a drag force on the rear seal will be present as a "thrust producer" on the bow seal. Only the differential force will have significance with respect to the total drag. It is anticipated that future testing will include the determination of total lift and drag on the rear seal, although this must follow a modification to suspend the entire seal from the hull through a system of load cells. The results of this paper should then allow determination of hydrodynamic drag present on the rear seal. A complete discussion of the various drags associated with the surface effect ship may be found in Refs. 2 and 3.

Following an accurate determination of drag forces present on various vessel components, primary areas of concern will be highlighted for future redesign considerations, and areas of low drag will be reaffirmed as positive features of hull performance.

II. METHOD OF INVESTIGATION

The rear seal of the XR-3 has a surface area exposed to the plenum of 120 inches in width and running 48 inches from the hingeline to the trailing edge. For the purposes of this project, internal stern seal pressure was established at 24.5 psf overpressure with a constant plenum overpressure of 23.5 psf. Seal surface static pressures were desired over a range of speeds from twelve knots to twenty-four knots, thus restricting the range to speeds at which the ship would be over the "secondary hump" referred to in Ref. 4.

In addition to the measurement of pressures, an accurate determination of actual seal surface shape was critical for satisfactory reduction of pressure data into lift and drag components.

Consideration was given to several techniques for obtaining the desired pressure data. First, a static pressure probe contained in a restraining channel attached to the surface of the seal and controlled from the deck of the XR-3 has the advantage of providing a complete vertical scan of the surface and allowing the ship to get over the secondary hump without subjecting the pressure probe to the associated flood of water through the plenum area during that transition. The primary disadvantage of this technique stems from the relative complexity of providing for control of its movement. Considerable modification to existing deck and sub-components would have been required. Further, there was a concern that the unknown shapes of the seal at various speeds might preclude smooth passage of the test probe through even a fairly flexible channel. Second, consideration was given to a permanent bank of flexible tubing attached at various intervals on the seal surface through which a constant back pressure in excess of plenum

overpressure would be maintained to prevent water from entering the system. Any change to this back pressure could then be claimed to be due to meaningful pressure indications on the surface of the rear seal. The difficulties associated with maintaining a constant backpressure through vented tubing while reading very small pressure changes along the seal surface, caused this system to be abandoned. The method finally adopted provides for utilization of backpressure on the static pressure tubes to clear the tubes of water following transition to cruise speeds over the hump. Once cleared, readings were taken directly from the surface at five inch intervals through a bank of ten tubes. Even the lowest of the pressure taps remained free of water once the velocity transition was accomplished. This lack of water is consistent with the observation of venting plenum air along the trailing edge of the rear seal. Following speed changes the lowest of the pressure tubes were again "blown" out to insure freedom from water blockage.

Following several series of runs at various speeds the bank of pressure tubes was moved from the centerline of the seal to a side location ten inches in from the side wall. Data was collected here in the same manner so that any lateral variations in seal pressure would be taken into account in the result.

The flexible nature of the rear seal presented a problem in determining the exact shape over which existing pressures would act. The location of the trailing edge of the seal and the hinge line itself were the only points known from which to determine seal shape, once underway. In order to obtain more data points on the shape of the critical top half of the seal, a closed circuit video camera was employed.

Although this installation required some modification

to the deck structure of the XR-3, considerable latitude was available as to selection of camera location, thereby allowing the modifications to be kept away from the areas of critical sub-components. A low light video camera (more completely described in the DESCRIPTION OF EQUIPMENT AND PROCEDURES section of this paper) was housed in a water tight lucite housing in the plenum area of the XR-3. Capability was provided for positioning of this camera so as to view most portions of the interior of the plenum including both bow and stern seals. A grid of dark, two inch squares was painted on the aft portion of the port interior side wall so that the curve of the stern seal surface area was shown across the grid. This system allowed an accurate picture of seal position to be made during operations with the only restriction being the limitation of available light at the aft most portions of the seal. As an illustrative example of this system Fig. 1 shows a Polaroid photograph of the seal and grid with the XR-3 sitting dead in the water.

III. DESCRIPTION OF EQUIPMENT AND PROCEDURES

A. REAR SEAL PRESSURE DATA

1. Apparatus

The ten flexible tubes employed for static pressure determinations were one-quarter inch inner diameter, color coded, plastic tubing. It was discovered in the early work of this project that the difficulty of clearing water from smaller inner diameter tubing made it impractical to use. The bank of tubing was attached to the flexible rear seal of the XR-3 through the use of clear silicone adhesive and tape. The ends of the tubing were cut so as to preclude any dynamic pressure, if present, from influencing the static pressure readings. The relative positions of the ten taps on the face of the stern seal are shown in Fig. 2. The bank of tubing was brought along the hingeline of the seal to the sidewall of the ship, around the end of the stern seal, onto the deck and forward fifteen feet to the cockpit area of the vessel. A twelve port scanavalve system was utilized at this point to provide a method of selectively acquiring and evaluating data from the various pressure taps on the seal. The scanavalve fed selected pressures to a signal amplifier package composed of a Grant model DCA8-3 amplifier, and then to the fourteen channel tape recorder data acquistion system described in Ref. 5. While data was being recorded, a visual readout to the cockpit was provided by taking the recorded signal directly from the tape output and sending it to a digital multimeter where the pressure was displayed in a millivolt analog. A schematic of this system is shown in Fig. 3.

2. Procedures for Static Pressure Data Collection

All test runs were made after transition to speeds beyond the "secondary hump". Following launch of the XR-3 calibration of test equipment was made and sufficient power added to accelerate into the speed regime of the

tests. Once stabilized after transition, the ten pressure tubes were backpressured with the use of compressed air carried onboard for that purpose. This compressed air was introduced to the lines at fittings located between the pressure taps and the scanavalve system. This technique prevented any possibility of damage to the seals of the scanavalve, or a possibility of damage to the sensitive pressure transducer. With the tubes cleared of water introduced during the transition phase, the XR-3 was stabilized at one of the five test speeds by direct readout of vessel speed from the tape acquisition system. The tape recorder was then started and each of the ten pressure taps was selected in turn through the scanavalve. Readings were taken from the lowest point on the seal to the highest, with a delay of approximately fifteen seconds allowing stabilization of the reading and recording of the data point manually in the cockpit.

Runs were made in this manner at twelve, fifteen, eighteen, twenty-one, and twenty-four knots. Between each run, following a speed change, the lowest three tubes were backpressured to ensure that water had not been reintroduced during the transition to the new speed. Three runs were made at each of the five speeds indicated, and two to three runs were made following a move of the tube bank to the side of the seal from the centerline. On the day data runs were made for the pressures at the side of the seal surface, Lake San Antonio was experiencing slight chop from wind conditions and the XR-3 was unable to sustain the twenty-four knot speed consistently enough to obtain data.

B. SEAL SHAPE DETERMINATION

1. Apparatus

The critical seal shape determination phase of this project was accomplished with a closed circuit low light video camera housed in a watertight lucite casing and

located approximately two feet to the right of centerline in the lift fan engine compartment. It was suspended by means of a stainless steel bar which extended from the camera housing up through the hull to the engine compartment. The camera position could be changed by moving the bar up or down and by twisting it up to 360 degrees in azimuth. The video signal was then brought forward to the monitor located between the two cockpit positions. The monitor consisted of a viewing port for the pilot, and a mounted Polaroid camera capable of photographing the display on the monitor at any time desired. The camera system was an oscilloscope camera modified by the project assistant, Mr. Michael Odell.

A reference grid was painted on the interior, port aft sidewall of the XR-3 at the location of the seal surface/sidewall interface. This grid ran from just aft of the hingeline rearward, and from the top of the seal to the bottom of the sidewall. The dark squares were two inches on each side and the spaces between them were one-half inch wide. This grid appeared most suitable for proper resolution on the video monitor while still providing sufficiently refined seal position indications.

The position of the trailing edge was determined mechanically by the use of a line physically attached to the trailing edge of the stern seal and brought forward over the deck to the cockpit area.

2. Procedures for Seal Shape Determination

The apparatus described above allowed observation of the seal position and wave interaction during operations. With the XR-3 stabilized at each of the five test speeds, the camera was positioned so as to pick up the left edge of the rear seal surface as it passed across the grid of two inch squares discussed above. Three photographs at each speed were taken to provide cross-checks for seal position.

The trailing edge position in inches above the keel was established at each speed by removing all slack in the line attached to the trailing edge of the seal surface and measuring the variation of line movement from a known position of the trailing edge measured with the XR-3 out of the water.

IV. RESULTS

A. SEAL SURFACE PRESSURES

The seal surface centerline pressure readings (in millivolts) are presented for each of fifteen runs in Table I. The surface pressures taken at the side of the seal are shown in Table II. for the nine runs accomplished. This raw data was reduced to average readings for each speed for each of the ten pressure taps. These averages are shown in Table III for the centerline location, and in Table IV for the side seal data.

The data indicated was then converted into pounds per square foot of overpressure. Since 1000 millivolts was calibrated to be fifty pounds per square foot of overpressure, readings were multiplied by .05 to obtain the data of Tables V and VI for centerline and side seal data respectively.

To determine the total lift and drag components present on the rear seal due to the static pressures, the readings of centerline and seal edge were again averaged to obtain a single value for each of the ten different vertical data positions on the face of the seal. The averaging of these readings considered the centerline reading to be valid over the center sixty inches of the seal and the symmetric seal edge readings to effect thirty inches on each side. The average values of the pressures at the ten vertical locations for the five test speeds are shown in Table VII.

The pressures of Table VII. were used to calculate forces generated at each of the ten positions on the seal. Each vertical position reading was applied over a five inch band of seal surface running the full 120 inches of seal width. The pressure at station 10 was assumed to operate over a three inch band thus completing the 48 inch curved

face of the seal. Thus for stations 1-9 the reading of Table VII. was multiplied by 4.16667 square feet of surface area (5"x120"/144sq."=4.16667) and the reading at station 10 was multiplied by 2.5 square feet (3"x120"/144sq."=2.5) The results of these computations are shown in Table VIII.

B. SEAL SHAPES

With the forces at each of the ten vertical stations of the seal determined, evaluation of seal shape was required at the various test speeds. This was accomplished by using the hingeline as a reference in the Poloroid photographs and matching point by point the crossing of the seal surface with the painted grid. A drawing was generated from these points, the hinge point, and the known trailing edge position. The resulting seal shapes for each of the five test speeds are shown in Figs. 4-7. Each of the ten test stations was located on these drawings and the angle between the tangent to the surface at these points and the horizontal was recorded at each location. These angles are listed in Table IX.

Once the geometry of the seal was determined, the forces of Table VIII were broken down into lift and drag components for each location on the seal surface and for each speed. These results along with the total lift and drag due to the static pressures are shown in Table X.

V. DISCUSSION OF RESULTS

The results of this report are broken into two parts. The first part will deal with the rear seal position determinations and the second with the lift and drag components and totals resulting from the static pressure measurements on the rear seal surface.

The seal shapes and positions shown in Figs. 4-7 may be easily compared. The expected lifting of the seal as the ship accelerates from the quasi-static condition to the region of testing beyond the "secondary hump" is clearly visible in Fig. 4. A more startling picture is shown in the comparison between the 12 knot and the 15 knot shape (Fig. 5). The aft part of the seal appears to have shifted downward in conjunction with a noticeable buckle in the first third of the seal surface. The static pressures measured at these two speeds increases slightly from the 12 to 15 knot runs and cannot explain a downward shift at the higher speed. It can only be supposed that at the lower speed, the increased hydrodynamic drag and lift at the trailing edge is responsible for the change. It may be noted that at the point of maximum differance in seal position the variance is just 1.5 inches. Once above 15 knots the seal shapes are vary similar at the various speeds, all showing the buckle developing between ten and fifteen inches aft of the hingeline. Variations in shape shown in the comparison of the runs at 18 and 24 knots (Fig. 6), show a maximum vertical variation in seal position of less than one inch. The location of the buckle at 24 knots may be seen to be forward of the 18 knot buckle, the result is a less "bowed" aft seal surface at the higher speeds. This characteristic may be attributable to the ever increasing volume and velocity of plenum air venting under the trailing edge, increasing aerodynamic drag and tending to pull the seal surface straighter. It should again be

recalled that at speeds above 12 knots the amount of water/seal contact is minimal while at 12 knots hydrodynamic considerations provide a possible explanation for the upward shift of seal position. The general location of the seal buckle shown at all test speeds is supported by the tabulated lift and drag results, by seal section, shown in Table X. It may be noted that on the first half of the seal surface, the half least affected by venting plenum air, the buckles occur in the vicinity of the high static pressure lifts. This occurs at station 8 for the 15,18, and 21 knot runs, and at station 9 for the 24 knot runs. In each case the lift decreases aft of these stations and drag increases.

The averaged data of Table III for the centerline runs, and of Table IV for the seal edge runs both show an ever decreasing overpressure from station 10 at the hingeline to station 1 near the bottom of the seal surface. The 24 knot reading at station 1 shows the effect of the venting plenum air in its negative value--indicating an underpressure at that point. The low readings consistently obtained at the bottom of the seal surface reflect the proximity of the part of the seal to the fast moving water surface and the accelerating plenum air prior to venting under the seal. The sudden rise at station 3 and the continual increases in pressure to the top of the seal reflect a movement away from the water surface and the subsequent gradual decrease in effect from plenum venting. The higher readings at the seal edge appears to result from the reduction of venting near the rigid sidewalls of the vessel. This phenomenon, visible from the XR-3's chase boat, would explain the slight variation in pressure distribution between various lateral locations along the seal.

The procedure used for determination of static pressures is clearly an approximation. Although the variations in readings between centerline and seal edge

positions was not great, sufficient difference exists to indicate that the actual seal surface pressure pattern will not be perfectly discribed by the simple averaging of the two readings. The purpose of this project, however, was to provide an insight into the relative magnitudes of the forces present from static pressures and to obtain for the first time a feel for the changes in seal shape which develop with the XR-3 actually underway. In this regard the project has been successfull. Variations in seal shape and position have been recorded as have the variances in static pressures both vertically and to a lesser extent horizontally.

The total drags and lifts computed and shown in Table X for the various test speeds have little value in themselves. As discussed in the introduction to this paper, the data will only become valuable with consideration to the entire ship's drag and lift when a similar analysis of the bow seal is accomplished, and the total drag of the stern seal is measured following a structural modification.

VI. CONCLUSIONS AND RECOMMENDATIONS

The results of this project, tabulated in Table X, provide the data necessary for the first step in evaluating the component of total ship's drag that is acting on the stern seal of the XR-3. After obtaining total stern seal lift and drag the hydrodynamic drag will be obtained by simple subtraction of the static pressure drag determined here.

Various indications were observed during the tests which provide starting points for further evaluation. The static pressure profiles obtained vary with speed primarily as the result of changes in the velocity and volume of plenum air venting under the seal, and due to the location of this venting. The variation of averaged pressure readings from station 3 to 10, shown in Table III, indicates that with increased speed the venting under the centerline of the seal decreases. This results from the stiffening of the seal as it is further displaced from the full down position. At the lower speeds the center of the seal is more flexible allowing more venting than when it is stiffened at the higher speeds. In addition, the seal-sidewall physical interference is a factor in preventing the venting of air near the sidewalls of the craft. This is substantiated by the data of Table IV at the seal edge, showing very little venting at 12 knots and a constant level of venting at the higher speeds.

Stern seal shapes have been shown to be far more complex than originally thought, and more rigid seals may need to be considered for higher plenum pressure operations. Analytical consideration of stern seal drags and lifts over the operating speed range of surface effect ships will not become feasible until more constant, less complex seal shapes can be established, or until satisfactory modeling

can be accomplished to accommodate the present ones.

It is recommended that the stern seal mounting be modified so as to allow total seal forces to be monitored during operation at the test speeds of this project. It is further recommended that a static pressure analysis be accomplished along the rear face of the XR-3's bow seal and a total force evaluation be accomplished on the bow seal as well.

With this data available a good evaluation of component lifts and drags will become possible and a clear determination can be made as to modifications necessary for higher speeds at lower power requirements.

Table I

Rear Seal Static Pressure-Centerline

Raw data-in millivolts

		12 Kts.	15 Kts.	18 Kts.	21 Kts.	24 Kts.
	Sta. 1	020	022	002	014	-035
	2	025	038	030	022	058
	3	421	440	469	484	480
	4	450	462	478	490	487
	5	462	474	483	492	506
Run 1	6	468	474	484	492	501
	7	471	475	483	491	503
	8	473	475	484	491	500
	9	476	477	485	492	498
	10	476	477	482	490	494
	Sta. 1	032	029	050	030	-070
	2	032	031	043	022	-040
	3	420	452	472	483	500
	4	458	468	481	491	497
	5	463	475	486	491	490
Run 2	6	468	477	488	492	496
	7	472	477	489	491	499
	8	472	478	488	491	498
	9	473	480	489	492	493
	10	474	480	488	490	490

Table I (Cont.)

		12 Kts.	15 Kts.	18 Kts.	21 Kts.	24 Kts.
	Sta. 1	032	030	040	025	-130
	2	032	042	050	031	025
	3	438	460	470	485	498
	4	455	475	474	487	493
	5	463	478	480	488	491
Run 3	6	465	480	482	491	492
	7	471	483	481	492	492
	8	472	483	482	492	491
	9	473	483	484	493	491
	10	473	481	484	491	490

Table II

Rear Seal Static Pressure-Seal Edge

in Millivolts (1000mV=50psf)

		12 Kts.	15 Kts.	18 Kts.	21 Kts.	24 Kts.
	Sta. 1	031	022	035	035	SEA
	2	037	030	040	042	STATE
	3	484	468	446	468	PRECLUDED
	4	486	470	468	489	24 KT.
	5	488	476	472	495	DATA
Run 1	6	492	478	480	502	
	7	492	485	484	499	
	8	500	490	489	500	
	9	496	493	490	502	
	10	496	496	487	502	
	Sta. 1	035	035	040	027	
	2	037	042	038	050	
	3	479	447	484	466	
	4	484	478	488	472	
	5	486	482	488	478	
Run 2	6	485	488	492	483	
	7	489	490	490	486	
	8	486	490	493	490	
	9	486	489	494	490	
	10	490	488	496	492	

Table III

Averaged Raw Data of Table I-in Millivolts

(1000mV=50psf)

	12 Kts.	15 Kts.	18 Kts.	21 Kts.	24 Kts.
Sta. 1	028	027	031	023	-078
2	030	037	041	025	014
3	426	451	470	484	493
4	454	468	478	489	492
5	463	476	483	490	496
6	467	477	485	492	496
7	471	478	484	491	498
8	472	479	485	491	496
9	474	480	486	492	494
10	474	479	485	490	491

Table IV

Averaged Raw Data of Table II-in Millivolts

(1000mV=50psf)

	12 Kts.	15 Kts.	18 Kts.	21 Kts.
Sta. 1	030	030	037	031
2	037	037	039	046
3	481	466	465	467
4	485	478	478	480
5	486	482	480	486
6	488	485	486	493
7	490	488	487	492
8	493	490	491	496
9	491	492	492	496
10	493	493	491	497

Table V

Average Rear Seal Static Pressure-Centerline

Values in #/sq.ft. Overpressure

		12 Kts.	15 Kts.	18 Kts.	21 Kts.	24 Kts.
Sta.	1	1.40	1.40	1.55	1.15	-3.90
	2	1.50	1.85	2.05	1.25	0.70
	3	21.30	22.55	23.50	24.20	24.65
	4	22.70	23.40	23.90	24.45	24.60
	5	23.15	23.80	24.15	24.50	24.80
	6	23.35	23.85	24.25	24.60	24.80
	7	23.55	23.90	24.20	24.55	24.90
	8	23.60	23.95	24.25	24.55	24.80
	9	23.70	24.00	24.30	24.60	24.70
	10	23.70	23.95	24.25	24.50	24.55

Table VI

Average Rear Seal Static Pressures-Seal Edge

Values in #/sq.ft. Overpressure

		12 Kts.	15 Kts.	18 Kts.	21 Kts.
Sta.	1	1.50	1.50	1.85	1.55
	2	1.85	1.85	1.90	2.30
	3	24.05	23.30	23.25	23.35
	4	24.25	23.90	23.90	24.00
	5	24.30	24.10	24.00	24.30
	6	24.40	24.25	24.30	24.65
	7	24.50	24.40	24.35	24.60
	8	24.65	24.50	24.55	24.80
	9	24.55	24.60	24.60	24.80
	10	24.65	24.65	24.55	24.85

Table VII

Total Static Pressure Values on Rear Seal

#/sq.ft. Overpressure

	12 Kts.	15 Kts.	18 Kts.	21 Kts.	24 Kts.
Sta. 1	1.45	1.45	1.70	1.35	-3.90
2	1.68	1.85	1.98	1.78	0.70
3	22.68	22.93	23.38	23.78	24.65
4	23.48	23.65	23.90	24.23	24.60
5	23.73	23.95	24.08	24.40	24.80
6	23.88	24.05	24.28	24.63	24.80
7	24.03	24.15	24.28	24.58	24.90
8	24.13	24.23	24.40	24.68	24.80
9	24.13	24.30	24.45	24.70	24.70
10	24.18	24.30	24.40	24.68	24.55

Table VIII

Static Pressure Forces on Rear Seal Sections

Values in lbs.

	12 Kts.	15 Kts.	18 Kts.	21 Kts.	24 Kts.
Band 1	6.04	6.04	7.08	5.63	-16.25
2	7.00	7.71	8.25	7.42	2.92
3	94.50	95.54	97.42	99.08	102.71
4	97.83	98.54	99.58	100.96	102.50
5	98.88	99.79	100.33	101.67	103.33
6	99.50	100.21	101.17	102.63	103.33
7	100.13	100.63	101.17	102.42	103.75
8	100.54	100.96	101.67	102.83	103.33
9	100.54	101.25	101.88	102.92	102.92
10	60.45	60.75	61.00	61.70	61.38

Table IX

Seal Shape Angles

Values in Degrees

	12 Kts.	15 Kts.	18 Kts.	21 Kts.	24 Kts.
Sta. 1	8.0	4.0	2.0	7.0	6.0
2	9.0	5.0	3.5	7.0	7.0
3	10.0	7.5	6.0	9.5	8.5
4	12.0	12.0	11.0	11.5	9.0
5	16.0	18.5	17.0	15.0	14.5
6	17.0	24.0	25.0	20.0	17.5
7	19.0	23.0	24.0	26.0	24.5
8	22.0	17.0	12.5	17.0	19.0
9	17.0	22.0	21.5	18.5	17.5
10	18.0	27.0	31.5	30.5	31.5

Table X

Lift and Drag Components

of

Static Pressure on Rear Seal

Values in lbs.

	12 Knots		15 Knots	
Sta.	Lift	Drag	Lift	Drag
1	6.0	0.8	6.0	0.4
2	6.9	1.1	7.7	0.7
3	93.1	16.4	94.7	12.5
4	95.7	20.3	96.4	20.5
5	95.0	27.3	94.6	31.7
6	95.2	29.1	91.5	40.8
7	94.7	32.6	92.6	39.3
8	93.2	37.7	96.5	29.5
9	96.1	29.4	93.9	37.9
10	57.5	18.6	54.1	27.6
	733.4	213.3	728.0	240.9

	18 Knots		21 Knots	
Sta.	Lift	Drag	Lift	Drag
1	7.1	0.2	5.6	0.7
2	8.2	0.5	7.4	0.9
3	96.7	10.2	97.7	16.4
4	97.8	19.0	98.9	20.1
5	96.0	29.3	98.2	26.3
6	91.7	42.8	96.4	35.1
7	92.4	41.1	92.1	44.9
8	99.3	22.0	98.3	30.1
9	94.8	37.3	97.6	32.7
10	52.0	31.9	53.2	31.3
	736.0	234.3	745.8	238.5

Table X (Cont.)

24 Knots

Sta.	Lift	Drag
1	-16.2	-1.7
2	2.9	0.4
3	101.6	15.2
4	101.2	16.0
5	100.0	25.9
6	98.5	31.1
7	94.4	43.0
8	97.7	33.6
9	98.2	30.9
10	52.3	32.1
	730.6	226.5

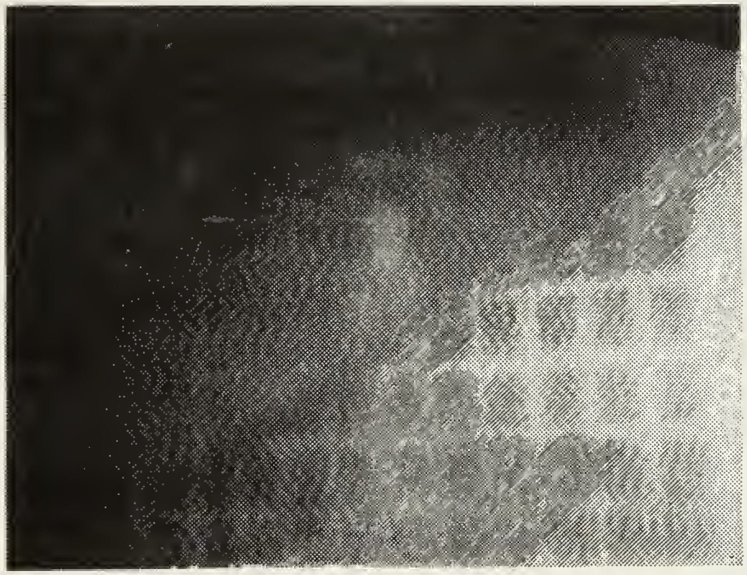


FIGURE 1. POLAROID PHOTOGRAPH SHOWING GRID AND SEAL

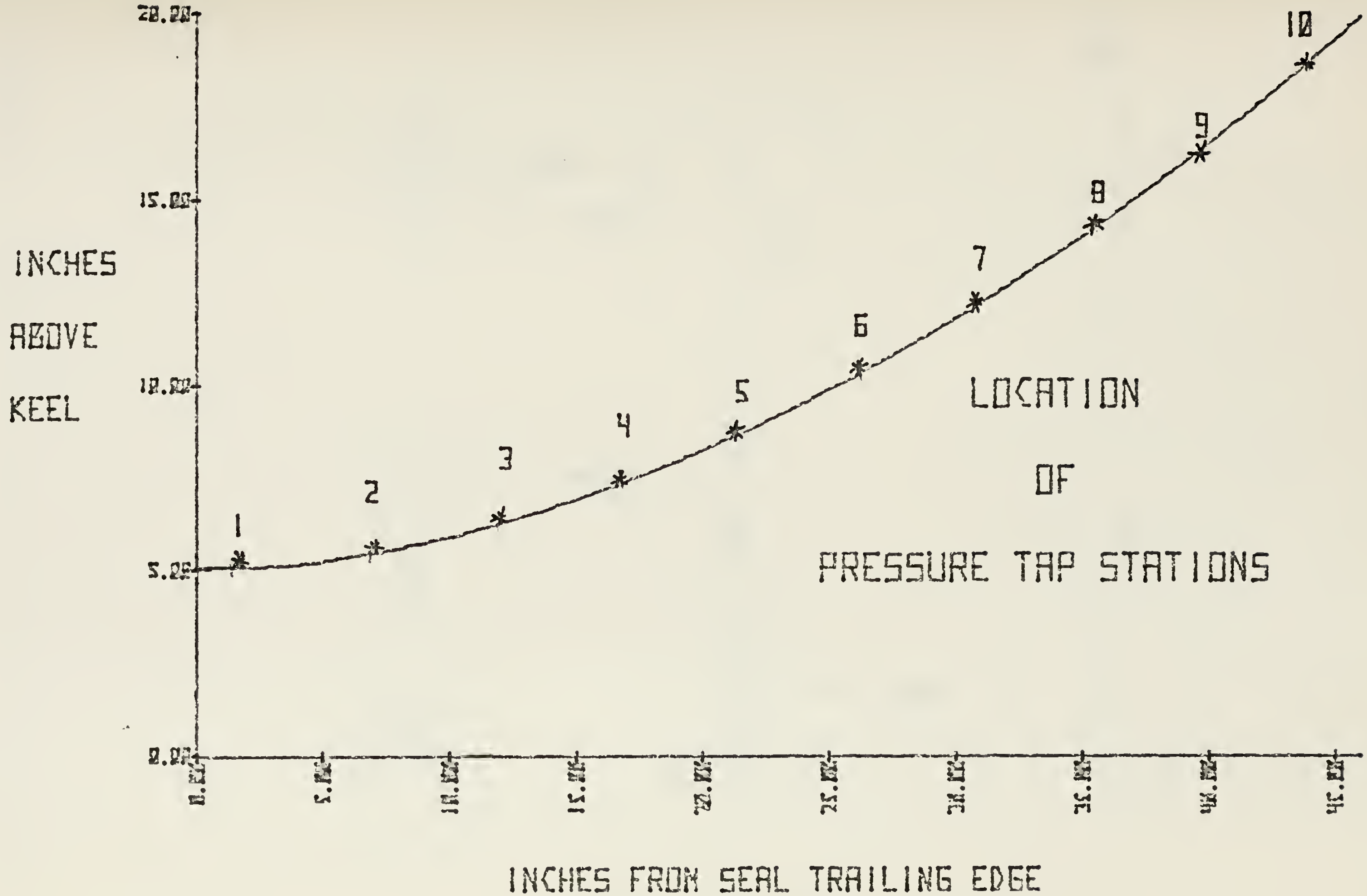


FIGURE 2. LOCATION OF PRESSURE TAP STATIONS

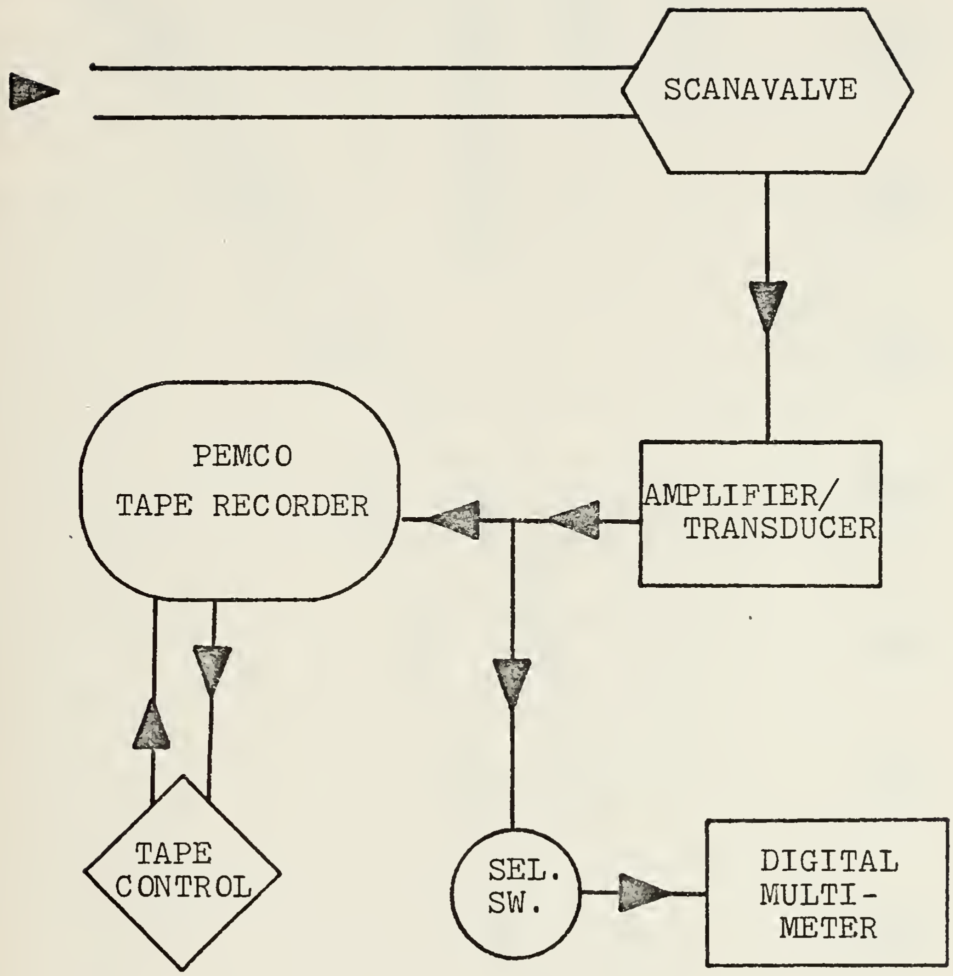


FIGURE 3. SCHEMATIC OF STATIC PRESSURE DATA SYSTEM

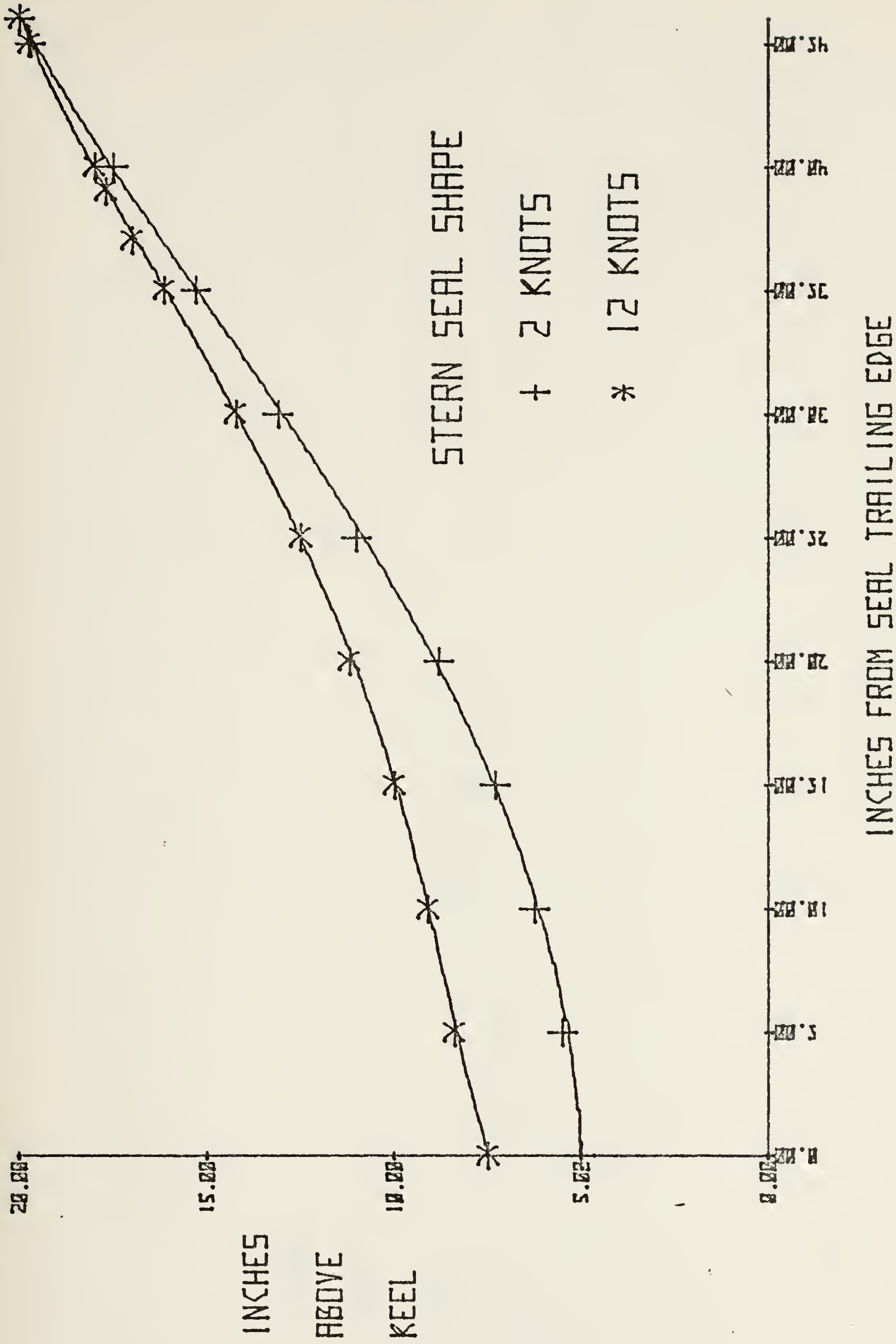

STERN SEAL SHAPE
+ 2 KNOTS
* 12 KNOTS
INCHES ABOVE KEEL
INCHES FROM SEAL TRAILING EDGE
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00

FIGURE 4

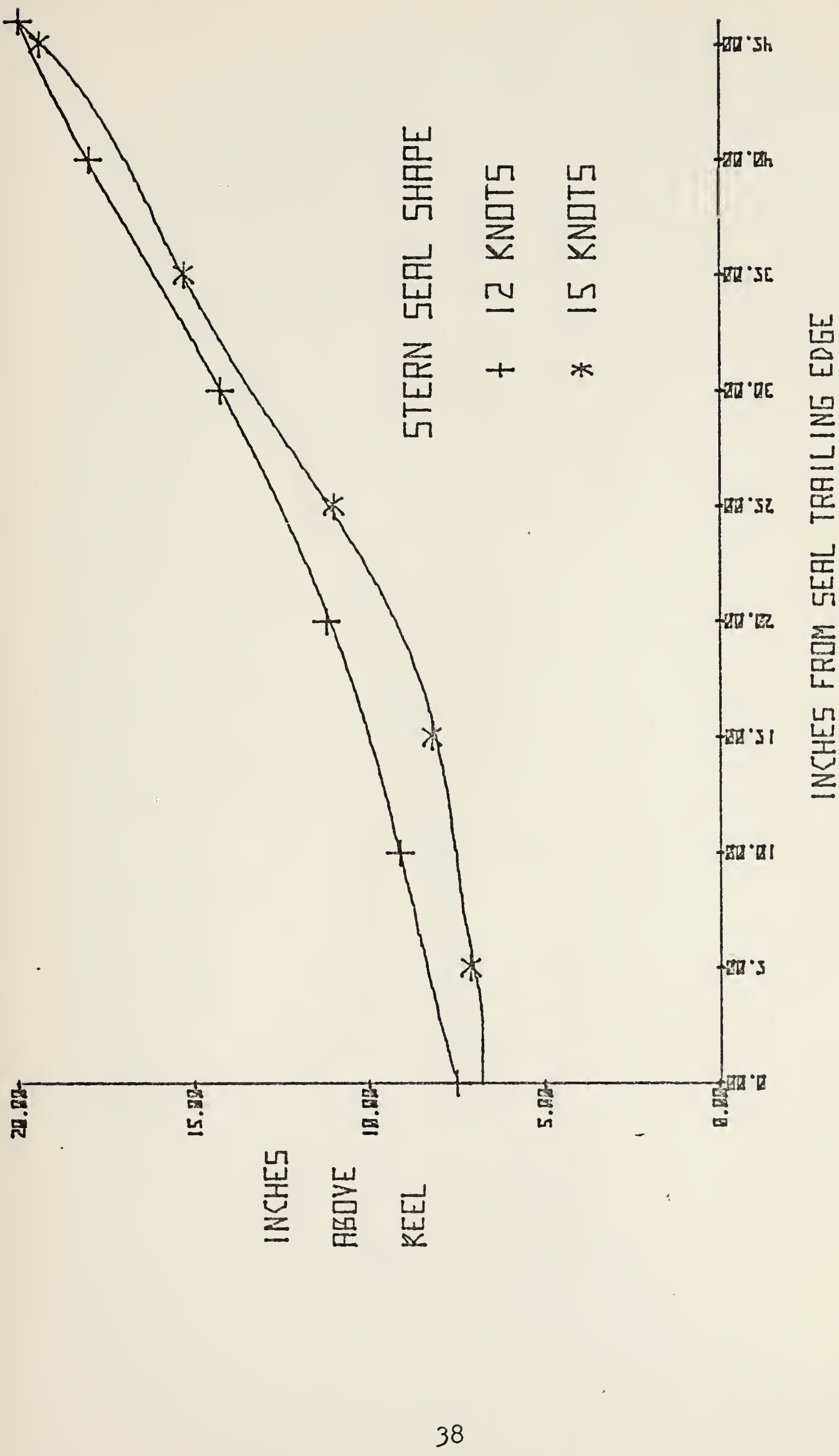

STERN SEAL SHAPE
+ 12 KNOTS
* 15 KNOTS
INCHES FROM SEAL TRAILING EDGE
INCHES ABOVE KEEL
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00

FIGURE 5

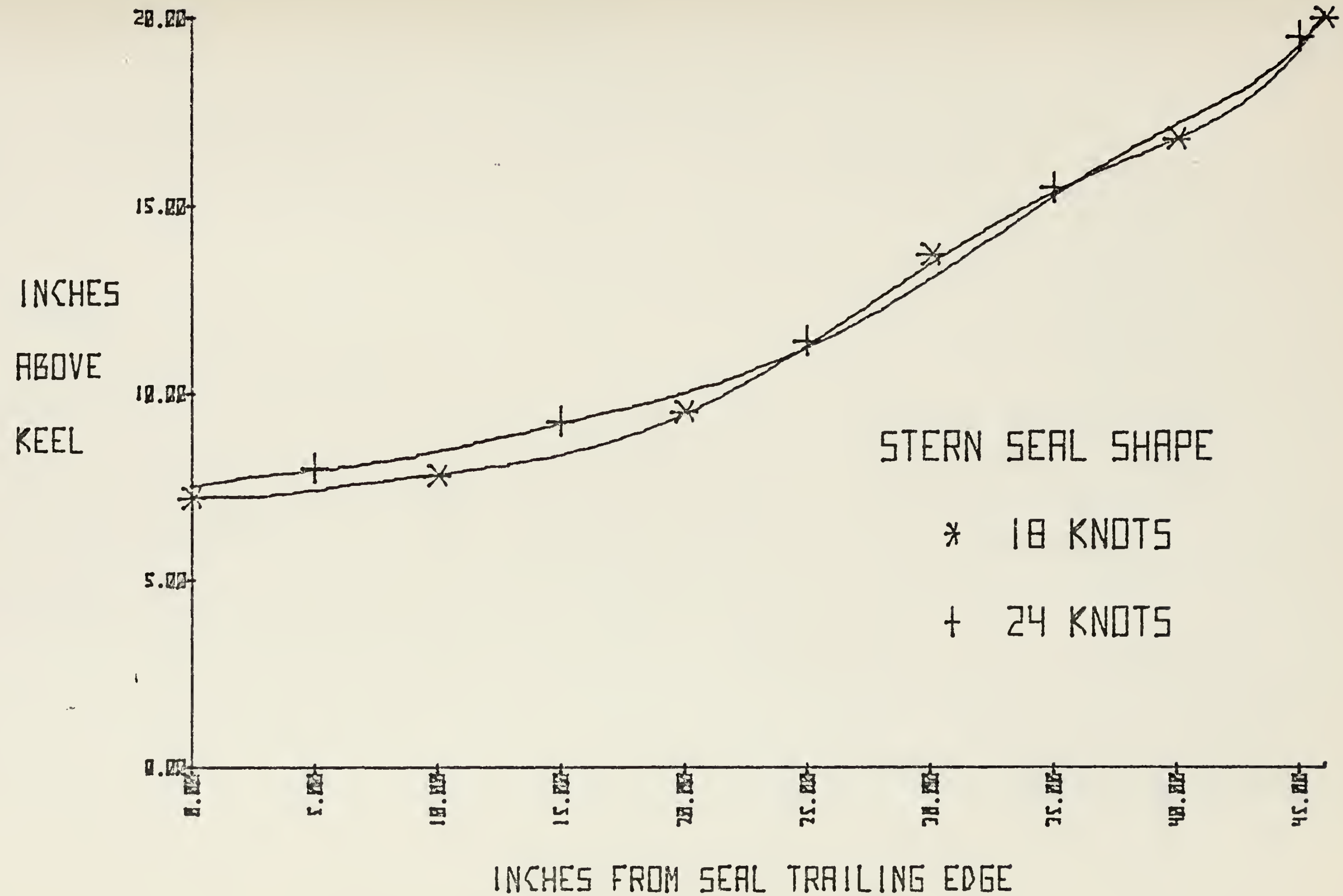
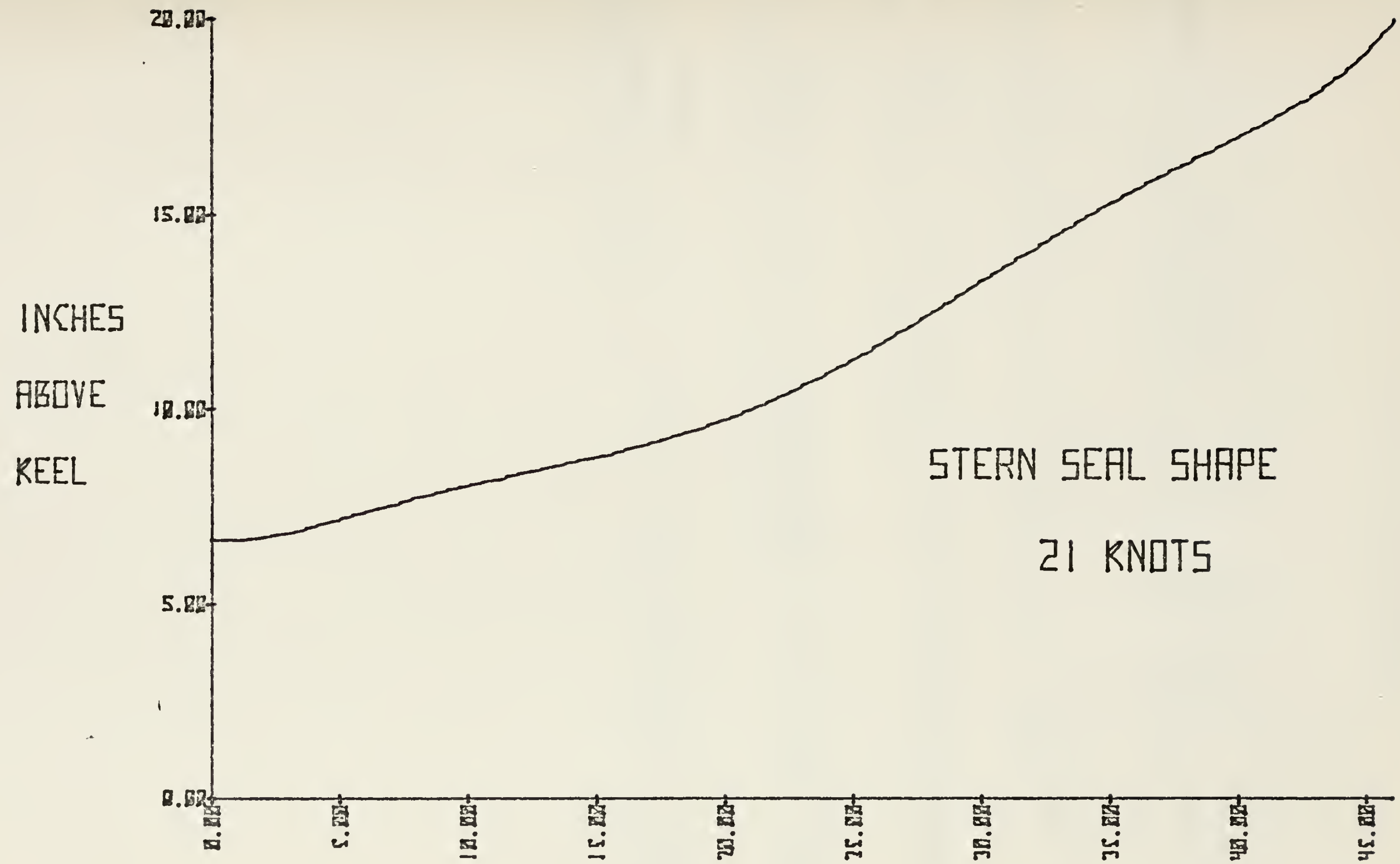

STERN SEAL SHAPE
* 18 KNOTS
+ 24 KNOTS
INCHES
ABOVE
KEEL
INCHES FROM SEAL TRAILING EDGE
20.00
15.00
10.00
5.00
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00

FIGURE 6



STERN SEAL SHAPE
21 KNOTS
INCHES ABOVE KEEL
20.00
15.00
10.00
5.00
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
INCHES FROM SEAL TRAILING EDGE

FIGURE 7

LIST OF REFERENCES

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